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PROBLEMS IN PROCESSING MULTIZONAL VIDEO INFORMATION AT SPECIALIZED COMPLEXES

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Multizonal video data obtained with the help of aerospace remote probe systems is characterized by numerically significant volumes and a high rate of delivery and renewal. The presence of the spectral criterion raises the possibility of automated processing of such data at a new qualitative level. Only a specialized complex constructed on the basis of the modern facilities of computer technology is capable of maintaining the operational mode of processing enormous blocks of data. The participation of the human operator in the processes of subject analysis of images permits on the whole a significant increase in the effectiveness of such a complex. /3*

The architecture of the image analysis complex and the ideology of its specialized mathematical provision are closely interrelated concepts, a sharp boundary between which cannot always be constructed. In fact, part of the analysis algorithms can be rather simply realized in the complex equipment, which permits significantly accelerating its "response" to the user-required form of the analysis. The central processor of the complex is freed of the necessity of performing routine operations on individual elements of the multizonal video data, and its response rate becomes a less significant parameter.

This work examines the requirements on the architecture of a specialized complex on the basis of a modern minicomputer and on its mathematical provision, which arise at different stages of digital analysis of multizonal images. It describes the principles of con- /4

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* Numbers in the margin indicate pagination in the foreign text.

structing a specialized operational system taking into account the peculiarities of the structure of the multizonal video data and also the specifics of servicing numerous peripheral input/output devices, image storage and operator terminals.

1. Structure of Multizonal Video Data

There are presently two forms of multizonal video data sensors which are placed on aerospace remote probe systems: electron-optical scanners and multizonal photographic cameras. We will be interested in the structure of the data delivered by these devices and also the form of the carriers on which the video data is stored after input into the analysis complex.

The line scanners record digital values of the brightness of each element of the earth's surface sequentially in several spectral ranges. The digital video data are recorded on a special high-density magnetic recorder along with auxiliary data. The logic structure of the magnetic recording of the scanner image is convenient for subsequent digital analysis since N spectral images of the object are necessarily "superimposed". Each element of the surface is represented by a sequence of N digital codes (bytes), which encode up to 256 gradations of spectral brightness. The number of lines of the scanner image recording depends on the specified scanning time.

Multizonal cameras produce a simultaneous photograph of some portion of the earth's surface in several spectral ranges. Special markers are applied for manual or automatic superposition of the photographs. Input of the photographs in digital code into the analysis complex is accomplished by means of a specialized peripheral device. Such a device transforms the values of the density of each of the N spectral photographs element by element into the corresponding digital codes (bytes). Scanning of each photograph at the photo input device is carried out line by line; the informativity of the original image can vary in accordance with the scanning aperture

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mounted on the device.

Analysis of the structure of multizonal video data permits distinguishing such general objects as "image element", "image line", "fragment" and "file". The set of N sequential bytes describing the spectral brightnesses of a resolvable element of the earth's surface is called the element of the digital multizonal image. The image line is formed from some sequence of elements. The dimensions of the lines are related to the characteristics of the specific receiver and video data delivery devices. The concept of file is related to the original image as a whole. The files form an archive of original images on magnetic tapes in the standard YeS (Unified System) computers. The file consists of some sequence of complete lines. The elements of the file can be examined only in sequential order. Any number of fragments comprising the archive of fragments on magnetic disks can be formed by the operating system from the original files by operator commands. The number of elements in a line and the number of lines of a fragment are strictly specified in the operating system and are determined by the volume of the high-speed two-dimensional direct-access memory in the display module of the analysis complex. The fragments are used by various subject analysis programs. The elements of the fragments can be examined both in sequential and random order. The length of the fragment element can vary from 1 to N in any selected combination from the N spectral ranges of the original file. If new images are the results of the analysis, they can form files (or fragments) which can either be output directly to a peripheral device or be combined into new archives on magnetic carriers. /6

One can define above and beyond the enumerated objects of the logic structure of the image a number of functions of the operating system, which permit working easily with the images at various stages of the digital analysis. The application of these functions by programs of the specialized complex must not depend on the auxiliary features of the specific peripheral devices with which these programs may be related. The presence of a standard set of input/output control functions in the operating system gives the applied

programs the means of unified contact with the images at the level of their logic structure.

2. Stages of Multizonal Video Data Analysis

We will consider the requirements on the architecture of the specialized complex and on the functions of its operating system, which arise at various stages of automated image analysis.

2.1. Input of Multizonal Images into the Complex

In view of the tremendous volumes of data, the original digital images are stored in the complex in large-capacity memories -- magnetic tape storage, by combining sequential-access files in the archive.

The multizonal scanner image is copied sequentially at input from the primary magnetic tape by forming the superimposed file on the complex tape. The program realization of the copying from the high-density continuous magnetic recorder to the start-stop recorder imposes rigid time requirements on the magnetic recorder interface /7 of the specialized complex. The development of special independent copying equipment is obviously the best solution of the scanner image input problem. This equipment can be supplemented with a specialized processor performing the standard radiometric correction of the digital image at the time of input and also with a simple device for visual recording (for example, on photographic paper).

The presence of a specialized peripheral device for digital input of photographs into the system does not give rise to program difficulties. However, the presently existing photo input devices (scanning densitometers) allow only sequential readout of the spectral photographs. It is usually required to form a "superimposed" file similar to the scanner file on magnetic tape for convenience in the subsequent subject analysis. Assembly of the digital recordings of individual spectral photographs into a unified multispectral file on tape is performed with the help of a standard complex program.

The assembly problem, which involves the identification of reference points, relative displacement, rotation of the photographs and correction of distortion of the photographic carrier, is very complicated. An estimate of the time expended by the complex in performing input and assembly leads to very pessimestic conclusions. The digital recording of six photographs from the MKF-6 camera with preservation of the resolution at input can occupy up to 12 magnetic tapes! Input and assembly of such blocks of data can be measured in tens of hours of machine time, even if the coordinates of the reference points are specified manually by the operator of the display screen (and not identified automatically). Thus, the creation of archives of the entire original multizonal digital photographs is hardly suitable. Only small fragments of photographs selected by the user should be subject to subject analysis. /8

2.2. Selection of Fragments

The operating system can select any number of fragments to be subject to operational analysis from the original superimposed files. Formation of the fragment occurs according to the following parameters indicated by the complex operator:

-- name of the original file;
-- number of the initial line;
-- number of the initial element;
-- set of the required spectral ranges.

The search for the required fragment is accomplished visually on the screen of the display module. The scale of the fragment (with respect to its scale on the original image) can be selected by the system with any integer multiple factor. For example, for the line length of an original file of 4096 x N bytes with 4096 lines, the entire file can be transformed into a fragment with a compression factor of 8 (for a display memory volume of 512 x 512 x N bytes).

One can assign a name to the fragment and add it to the archive of fragments on magnetic disks. The fragment can be delivered to the display module memory and subsequent analysis will be carried

out by the display module in the semi-independent mode with active participation of the operator and under constant visual control.

2.3. Corrections and Geometric Transformations

Brightness correction of the digital image usually reduces to the simplest integral transformation of each element of the original file. The element-by-element linear transformation of the original file generates an output file with spectral brightness corrected. Since the arguments of such a transformation are integers in the range from 0 to 255, it can be realized by the tabular method (look-up tables). The brightness correction from the tables can be easily organized instrumentally and integrated into the architecture of the display module of the complex. /9

Geometric correction is performed mainly on the scanner images. This is the correction of a number of errors caused by the structure of the instrument, rotation of the earth, angular drift of the carrier object, etc. It is desirable to carry out such a correction onboard directly. If the errors are small, they can be corrected either by the special processor of the independent scanner file input equipment or by a simple standard complex program.

Geometric transformations of images (without analysis of the spectral criterion) are carried out, as a rule, to bring the image to some cartographic projection. The coordinates of several reference points of the fragment to be transformed are indicated by the operator on the display screen. The geographic coordinates of these points are usually known and can be stored by the operating system. In this case, the element-by-element transformation of the fragment into the specified projection is carried out according to simple power polynomials. The operating system provides fast direct access to the elements of the fragment to be transformed.

2.4. Subject Analysis

Subject analysis is the most complicated stage of machine anal-

ysis of multizonal images. The algorithms of the applied programs for recognition, classification, compilation of subject charts, resolution of contours, calculation of areas, etc. require very significant computations. Operator control of the course of subject analysis can significantly accelerate the performance of certain programs and, moreover, the recognition problem, being based on analysis of texture and geometric criteria, can be posed only with "operator-computer" dialog. /10

The analysis and classification according to spectral criteria yield more easily to automation. The fragment to be analyzed is represented by spectral brightnesses (integers from 0 to 255) in three-dimensional space with coordinates I -- line number, J -- element number and N -- number of the spectral range. The values of I and J for the fragment do not exceed the value K for a volume of the two-dimensional display memory of K x K x N bytes. A small range of variation of the arguments permits realizing instrumentally tabular calculation of any functions of the spectral brightnesses, while the presence of N-input summators permits calculating linear combinations of the obtained values of the tabular functions. Such an approach raises the possibilities of the display module of the complex to a new qualitative level, while retaining the convenience and speed of vizualization of the results of the semi-independent analysis.

A carefully thought-out architecture of the display module permits realization instrumentally of certain algorithms for spectral criterion classification, calculation of the ratio of spectral channels, performance of any form of linear transformation of the fragment, etc. is a very short time (the order of several seconds).

Among the subject analysis algorithms are also those which require large dimensions of the operational memory and cumbersome calculations. A specialized complex on a minicomputer basis is not suited for programmed realization of these algorithms. One should use general-purpose machines or develop specialized processors performing the specific calculation functions for solving such problems.

2.5. Output and Visualization of the Analysis Results

The results of video data analysis in digital form can form new files (or fragments) of images. The traditional results of machine /11
analysis (numerical tables, graphs, etc.) can also be obtained. The possibilities of visualizing the obtained results are determined by the set of specialized peripheral devices connected to the complex. Such devices include:

-- devices for output of the digital image to a photographic carrier;

-- plotters, alpha-numeric and half-tone printers;

-- television monitors of the display module with attachments for obtaining hard copy.

The magnetic tapes with the images obtained as a result of analysis at the specialized complex can be transmitted for further analysis to other systems including general-purpose computers.

3. Composition of the Specialized Complex Equipment

Consideration of the stages of digital analysis of multizonal video data permits determining the required configuration of the specialized complex. Such a complex can be based on a minicomputer with average parameters for the response rate (the order of 500,000 per second) and operational memory volume (the order of 64K bytes). The minicomputer must be provided with several sequential-access memories (magnetic recorders) and direct-access memories (magnetic disks or drums). The volume of the peripheral memory must be very large; for example, the length of the line of a superimposed multispectral digital photograph from the MKF-6 can reach 24K bytes!

The system assembly may include the following specialized peripheral devices:

-- scanning densitometer for digital input of photographs;

-- device for output of images to a photographic carrier; /12

-- scanner image input equipment;

-- plotter, alpha-numeric and half-tone printers.

The display module occupies a special place among the peripheral devices of the complex. The display system (the operator terminal) must be equipped, at a minimum, with:

-- fast direct-access memory with regeneration (refresh-memory) for storage of a single fragment;

-- unit for readback of fragment elements from the refresh-memory;

-- alpha-numeric and graphical output unit;

-- television monitors (color and/or b/w);

-- device of the "moving cursor" or "light pen" type for readout of display image coordinates;

-- functional keyboard to simplify the work of the complex operator;

-- programmable look-up tables and N-input summators.

The minicomputer must permit connection of a broader set of peripheral devices and have the possibility of controlling several operator terminals simultaneously in the time-share mode.

4. Specialized Operating System

The developed model of the operating system oriented toward analysis of multizonal video data at a specialized complex is called upon to solve the following basic problems:

-- to provide applied programs of all stages of digital analysis by means of a convenient unified contact with the images at the logic level;

-- to provide the mode of simple dialog between the complex operator and the library of standard and applied analysis programs and the related data flows. /13

A unified input/output control system has been developed to solve the first problem. The set of functions of this system is left to the applied programs; their application does not depend on the number and types of peripheral devices connected to the given version of the specialized complex.

Dialog with the operator, starting of the applied programs and connection of the data flows of the programs to the required devices (files, fragments) in the required mode are performed by the operating system monitor. The same program can operate with different input, output and visualization devices depending on the wishes of the operator. The image files and fragments on magnetic carriers are serviced by the specialized file system.

The operating system is provided with the possibility of accumulating a library of applied programs and allows connection of new specialized devices to the complex.

The operating system contains the means for programming the display module for performing its required functions in the semi-independent mode.

The first version of the described model of the operating system has been introduced into experimental operation in the specialized complex "Optronics" (U.S.). A small experimental library of programs for analyzing multizonal video data has been created. Although mainly research and methodological problems were posed in realizing the first version, it was found to be quite efficient and suitable for practical application.

A second realization of the operating system model in the "Optronics" complex is in the adjustment process in which the main consideration is being given to servicing the display module. /14